NASA Earth Science Decadal Survey Missions

Overview in preparation for the TIWG Decadal Survey Use Case Workshop (Thursday July 22, 2010)

- The Decadal Survey provides scientific priorities indirectly through a time sequencing of recommended missions. It is a first-ever comprehensive survey of all Earth sciences that could benefit from spaceborne observations. The study was requested and supported by NASA, NOAA, USGS. The final NRC Report was released 15 January 2007.
- Objective of the Decadal Survey
  - Supporting activities to support national needs for research and monitoring of the dynamic Earth system during the next decade.
  - Identify important directions that should influence planning for the decade beyond.

Recommendations

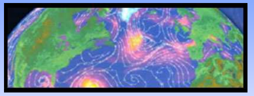
- Technology development in support of missions
  - NASA: invest in both mission-focused and cross-cutting technology development to decrease risk in missions and promote cost reduction across multiple missions
- Leverage International Efforts
  - Restructure or defer missions if international partners select missions which meet most of the measurement objectives of recommended missions then a) establish data access agreements, and b) establish science teams
  - Where appropriate, offer cost-effective additions to international missions that help extend the values of those missions
- Manage Technology Risk
  - Sequence missions according to technological readiness and budget risk factors ... technological investments should be made across all recommended missions
  - If there are insufficient funds to execute the missions in the recommended timeframes, it is still important to make advances on the key technological hurdles.
  - Establish technological readiness through documented technology demonstrations before mission development phase.

	Decadal Survey Mission	Mission Description	Orbit	Instruments
Phase 1	**CLARREO (NASA portion)**	Solar and Earth radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer
	SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer
	ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter
	DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter
Phase 2	**HyspIRI**	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer
	ASCENDS	Day/night, all-latitude, all-season CO2 column integral for climate emissions	LEO, SSO	Multifrequency laser
	SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar
	GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers
	ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiagnle polarimeter Doppler radar
Phase 3	**LIST**	Land surface topography for landsat hazards and water runoff	LEO, SSO	Laser altimeter
	PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW arrary spectrometer
	GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system
	SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers
	GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer
	3-D Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar

ICESat II : Ice, Cloud, and Land Elevation Satellite

The ICESat mission will provide multi-year elevation data needed to determine ice sheet mass balance as well as cloud property information, especially for stratospheric clouds common over polar areas.

CLARREO : Climate Absolute Radiance and Refractivity Observatory

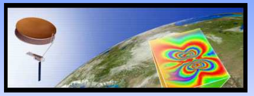


CLARREO is a climate-focused mission that will become a key element of the climate observing system.

SMAP: Soil Moisture Active Passive

SMAP will provide global measurements of soil moisture and its freeze/thaw state. These measurements will be used to enhance understanding of processes that link the water, energy and carbon cycles, and to extend the capabilities of weather and climate prediction models.

DESDynI : Deformation, Ecosystem Structure and Dynamics of Ice



Earth's surface and vegetation cover are constantly changing on a wide range of time scales. Measuring these changes globally from satellites would enable breakthrough science with important applications to society.

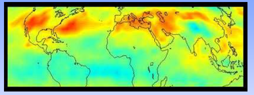
SWOT : Surface Water Ocean Topography

The SWOT Satellite Mission and its wide-swath altimetry technology is a means of completely covering the world's oceans and freshwater bodies with repeated elevation measurements.

HyspIRI : Hyperspectral Infrared Imager

HyspIRI data will be used for a wide variety of studies primarily in the Carbon Cycle and Ecosystem and Earth Surface and Interior focus areas.

ASCENDS : Active Sensing of CO2 Emissions over Nights, Days, and Seasons



ASCENDS will provide improved ability to predict/model long-term changes in the climate cycle based both on the understanding of the natural processes driving the variability of natural carbon sources and sinks, and on the transport of carbon through the atmosphere.

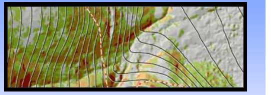
GEO-CAPE : Geostationary Coastal and Air Pollution Events

The solar backscatter data will provide aerosol optical depth information for assimilation into aerosol models and downscaling to surface concentrations.

ACE : Aerosol - Cloud - Ecosystems

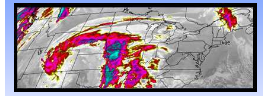
ACE will help to answer emerging fundamental science questions associated with aerosols, clouds, air quality and global ocean ecosystems.

LIST : Lidar Surface Topography



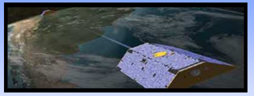
This global set of data will serve users and researchers from a wide array of disciplines that need elevation and terrain information.

PATH : Precision and All-Weather Temperature and Humidity



The improvement of our understanding of weather processes and phenomena is crucial in gaining an understanding of the Earth system.

GRACE II : Gravity Recovery and Climate Experiment



GRACE II will continue to provide detailed measurements of Earth's gravity field which will lead to discoveries about gravity and Earth's natural systems.

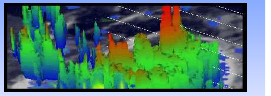
SCLP : Snow and Cold Land Processes

Measurements of snow accumulation are critical to studies of the changes in the total volume of snow and ice.

GACM : Global Atmospheric Composition Mission

GACM will enable scientists to better understand the relationship between atmospheric ozone distribution and the factors that alter it.

3D-Winds : 3-Dimensional Tropospheric Winds from Space-based Lidar



3D-Winds will study tropospheric winds for weather forecasting and pollution transport.

ICESat-2 : Ice, Cloud, and Land Elevation Satellite-2

ICESat-2 is the 2nd-generation of the orbiting laser altimeter ICESat scheduled for launch in late 2015.

The ICESat mission will provide multi-year elevation data needed to determine ice sheet mass balance as well as cloud property information, especially for stratospheric clouds common over polar areas.

Science Objectives

- Quantifying polar ice-sheet contributions to current and recent sea-level change and the linkages to climate conditions.
- Quantifying regional signatures of ice-sheet changes to assess mechanisms driving those changes and improve predictive ice sheet models.
- Estimating sea-ice thickness to examine ice/ocean/atmosphere exchanges of energy, mass and moisture.
- Measuring vegetation canopy height as a basis for estimating large-scale biomass and biomass change.
- Enhancing the utility of other Earth observation systems through supporting measurements.

Design

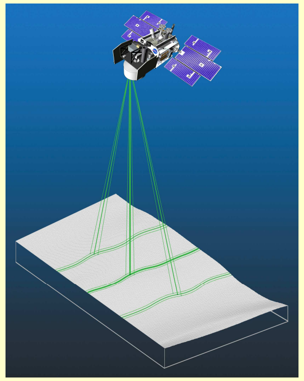
In contrast to the ICESat design, ICESat-2 will use a micro-pulse multi-beam approach. This provides dense cross-track sampling to resolve surface slope on an orbit basis.

The sensor will have a high pulse repetition rate of 10 kHz (exact number still TBD) which generates dense along-track sampling of about 70 cm.

This concept has advantages over ICESat of improved elevation estimates over high slope areas and very rough (e.g. crevassed) areas and improved lead detection for sea ice freeboard estimates.

Orbit: LEO, Non-SSO

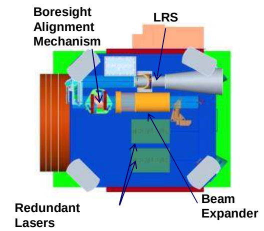
Instruments: Laser altimeter

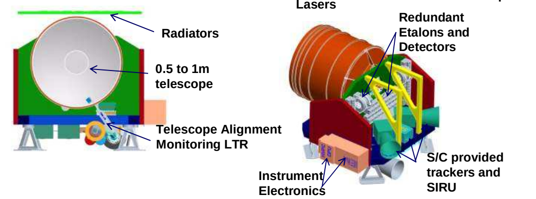


Instrument Overview

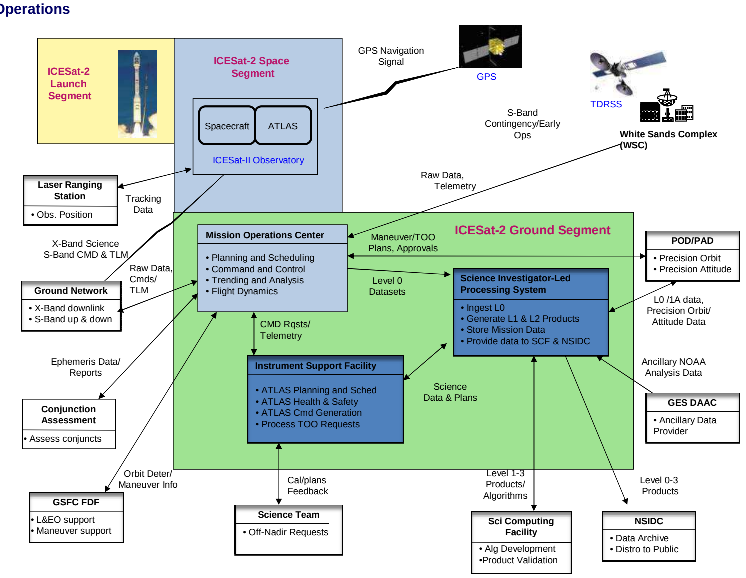
Multi-beam Micropulse Laser Altimeter

- Single laser beam split into 9 beams
- 10 m ground footprints
- 10 kHz rep. rate laser (~1mj)
- Multiple detector pixels per spot
- On-board boresight alignment system
- Laser Reference System gives absolute laser pointing knowledge





Ground Operations



CLARREO : Climate Absolute Radiance and Refractivity Observatory

CLARREO is a climate-focused mission that will become a key element of the climate observing system. The foundation for CLARREO is the ability to produce irrefutable climate records through the use of exacting on-board traceability of the instrument accuracy. Spectral visible and infrared radiances and GPS Radio Occultation (GPSRO) refractivities measured by CLARREO will be used to detect climate trends and to test, validate, and improve climate prediction models.

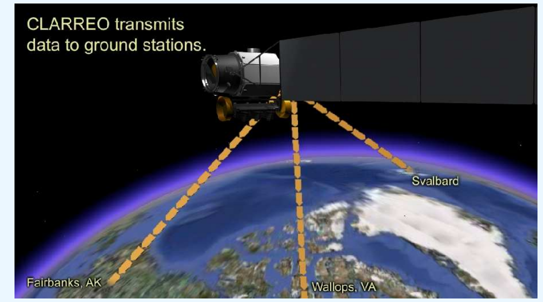
Mission Objectives:

Initiate an unprecedented, high accuracy record of climate change that is tested, trusted and necessary for sound policy decisions. Establish a record of direct observables with high accuracy and information content necessary to detect long-term climate change trends and to test and systematically improve climate predictions.

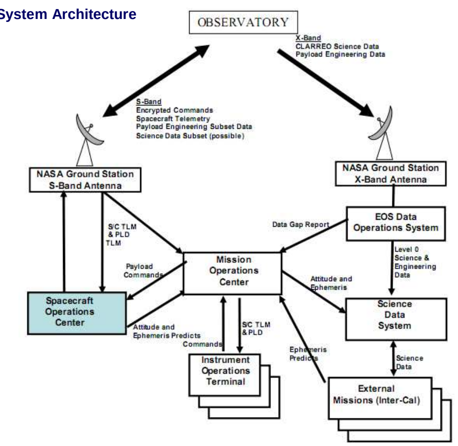
Observe SI traceable, spectrally-resolved radiance and atmospheric refractivity with the accuracy and sampling required to assess and predict the impact of changes in climate forcing variables on climate change.

Orbit: LEO

Instruments: Absolute, spectrally- resolved interferometer



Ground System Architecture



CLARREO will advance climate science in the following areas:

Improve assessment of climate predictions for public policy

- Creation of a benchmark climate record that is global, accurate in perpetuity, pinned to international standards and can be used to develop trusted and tested climate forecasts is necessary for the decision support structure to effectively respond to climate change. CLARREO will provide this by measuring solar reflected and infrared emitted high spectral resolution to benchmark radiance climate data records, to test climate model predictions, improve climate change fingerprinting, and attribution.

Provide climate accuracy calibration for operational sensors

- CLARREO will serve as an orbiting calibration observatory to calibrate other solar and infrared space-borne sensors, thereby improving climate accuracy of a wide range of sensor measurements across the Earth observing system.

Dramatically reduce the effects of data gaps

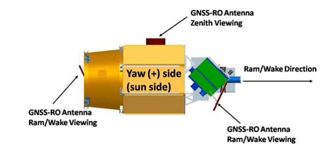
- The absolute accuracy of CLARREO, when used to calibrate other sensors in orbit, will dramatically reduce the impact of data gaps on decadal change data records across many climate variables.

Provide the first space-based measurements of the Earth's far infrared spectrum

- CLARREO will open a new window to 50% of the Earth's infrared spectrum with key information on water vapor feedback, cirrus radiative forcing, and the natural

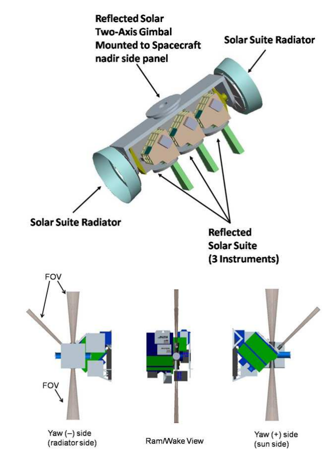
CLARREO Instruments

The CLARREO mission is currently envisioned to consist of two duplicate observatories each carrying a payload of one infrared instrument suite, one reflected solar instrument suite and a Global Navigation Satellite System Radio Occultation (GNSS-RO) instrument system.

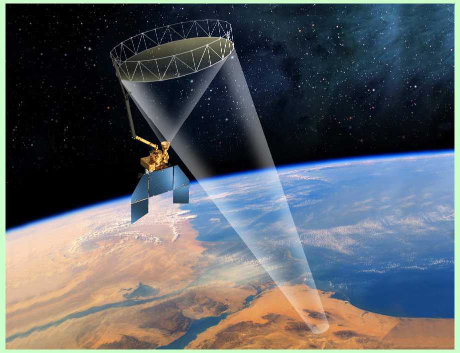


The CLARREO Payload Elements include:

- "Reflected Solar (RS) Suite" consisting of three pushbroom hyperspectral grating imagers covering 320-2300 nanometers combined into a single instrument package and pointed by a two-axis gimbal,
- "Infrared (IR) Suite" consisting of a Fourier Transform Spectrometer (FTS) covering 5-50 microns (2000-200 cm-1) and an on-orbit calibration and verification system,
- "Global Navigation Satellite System–Radio Occultation (GNSS-RO)" receiver capable of RO measurements using GPS, GLONASS, and Galileo navigation systems.



SMAP: Soil Moisture Active Passive



SMAP will provide global measurements of soil moisture and its freeze/thaw state. These measurements will be used to enhance understanding of processes that link the water, energy and carbon cycles, and to extend the capabilities of weather and climate prediction models.

Science Objectives

SMAP will provide a capability for global mapping of soil moisture and freeze/thaw state with unprecedented accuracy, resolution, and coverage. SMAP science objectives are to acquire space-based hydrosphere state measurements over a three-year period to:

- Understand processes that link the terrestrial water, energy and carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Enhance weather and climate forecast skill
- Develop improved flood prediction and drought monitoring capabilities

SMAP Data Products

The SMAP baseline science data products are shown in the table below. These data products will be made available through a NASA-designated data center. The products will conform to the HDF-5 standard.

Data Product Short Name	Short Description	Spatial Resolution	Grid Spacing	Latency*
L1A_Radar	Radar raw data in time order	NA	NA	12 hours
L1A_Radiometer	Radiometer raw data in time order	NA	NA	12 hours
L1B_S0_LoRes	Low resolution radar σ_o in time order	5x30 km	NA	12 hours
L1B_TB	Radiometer T_B in time order	40 km	NA	12 hours
L1C_S0_HiRes	High resolution radar σ_o (half orbit, gridded)	1x1 km to 1x30 km	1 km	12 hours
L1C_TB	Radiometer T_B (half orbit, gridded)	40 km	36 km	12 hours
L2_SM_P	Soil moisture (radiometer, half orbit)	40 km	36 km	24 hours
L2_SM_A/P	Soil moisture (radar/radiometer, half orbit)	9 km	9 km	24 hours
L3_F/T_A	Freeze/thaw state (radar, daily composite)	3 km	3 km	36 hours
L3_SM_P	Soil moisture (radiometer, daily composite)	40 km	36 km	36 hours
L3_SM_A/P	Soil moisture (radar/radiometer, daily composite)	9 km	9 km	36 hours
L4_SM	Soil moisture (surface & root zone)	9 km	9 km	7 days
L4_C	Carbon net ecosystem exchange (NEE)	9 km	1 km	14 days

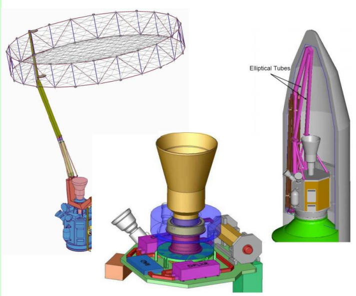
* SMAP L2 science requirements. Mean latency under normal operating conditions. The SMAP project will make a best effort to reduce these latencies.

Instrument Overview

The SMAP instrument architecture incorporates an L-band radar and an L-band radiometer that share a single feedhorn and parabolic mesh reflector. The reflector is offset from nadir and rotates about the nadir axis at 14.6 rpm, providing a conically scanning antenna beam with a surface incidence angle of approximately 40˚. The reflector has a diameter of 6 m, providing a radiometer footprint of 40 km. The real-aperture radar footprint is 30 km, defined by the two-way antenna beamwidth.

To obtain the desired high spatial resolution the radar employs range and Doppler discrimination. The radar data can be processed to yield resolution enhancement to 1-3 km spatial resolution.

The science goal is to combine the attributes of the radar and radiometer observations in terms of their spatial resolution and sensitivity to soil moisture, surface roughness, and vegetation. Soil moisture will be estimated optimally at a resolution of 10 km and freeze-thaw state at a resolution of 1-3 km.



DESDynI : Deformation, Ecosystem Structure and Dynamics of Ice

Earth's surface and vegetation cover are constantly changing on a wide range of time scales. Measuring these changes globally from satellites would enable breakthrough science with important applications to society.

Mission Objectives:

- Determine the likelihood of earthquakes, volcanic eruptions, and landslides.
- Predict the response of ice sheets to climate change and impact on the sea level.
- Characterize the effects of changing climate and land use on species habitats and carbon budget.
- Monitor the migration of fluids associated with hydrocarbon production and groundwater resources.

Orbit:LEO, SSO

Instruments: L-band InSAR, Laser altimeter

DESDynI Data Products

Instrument DESDynI	Data Product *All data should be georeferenced*
Lidar	
Elevation profiles	Digital Elevation Model (DEM) for precise elevation maps Sea ice thickness
Waveform fused with SAR	Aboveground biomass at 1 hectare resolution
Waveform	Vertical vegetation structure to ±1m
Radar	
Interferograms	3D time dependent vector surface deformation
Permanent scatters	2D/3D time dependent surface motions, sea ice motion
Polarimetric SAR/InSAR	Aboveground biomass
Backscatter	Coastal winds, biomass, oil slicks/seeps
SAR/InSAR	Landscape heterogeneity
SAR coherence	Forest disturbance maps

Source: Report of the DESDynI Applications Workshop, Oct 2008

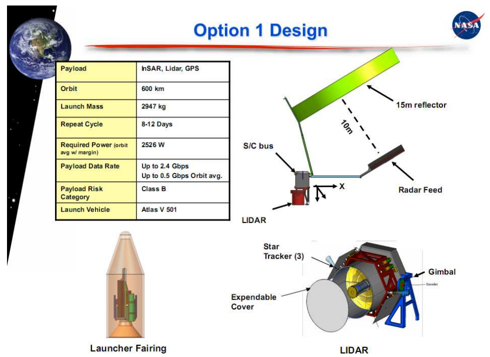
Mission Concept

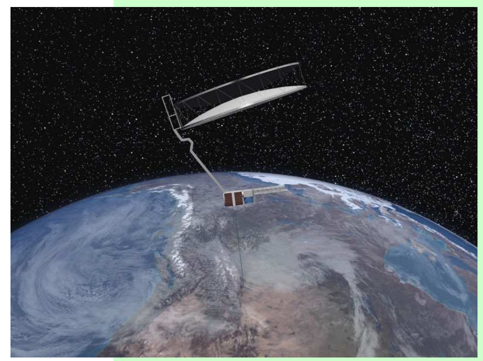
This mission combines two sensors that, taken together, provide observations important for solid-Earth (surface deformation), ecosystems (terrestrial biomass structure) and climate (ice dynamics). The sensors are:

- L-band Interferometric Synthetic Aperture Radar (InSAR) system with multiple polarization, and
- Multiple beam lidar operating in the infrared (~ 1064 nm) with ~ 25 m spatial resolution and 1 m vertical accuracy.

The mission using InSAR to meet the science measurement objectives for surface deformation, ice sheet dynamics, and ecosystem structure has been extensively studied. It requires a satellite in 700-800 km sun-synchronous orbit in order to maximize available power from the solar arrays. An eight day revisit frequency balances temporal decorrelation with required coverage. Onboard GPS achieves cm-level orbit and baseline knowledge to improve calibration. The mission should have a 5 year life time to capture time-variable processes and achieve measurement accuracy.

The applications data products required from DESDynI are similar to those required to meet the science goals of the mission. There are additional coverage goals for observing aquifers, reservoirs, and coastal oceans and flooding. The data latency, however, is much lower than that required for the science observations, particularly for hazard response. Emergency responders would benefit from quick-look products, even if they have degraded accuracy or resolution. The data products also need to be accessible and easily ingestible into other analysis systems. Web services with a clear workflow are recommended.





HyspIRI : Hyperspectral Infrared Imager

HyspIRI data will be used for a wide variety of studies primarily in the Carbon Cycle and Ecosystem and Earth Surface and Interior focus areas.

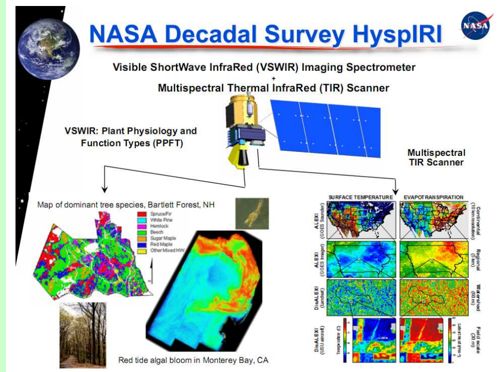
The HyspIRI Project will implement a spaceborne Earth observation mission designed to collect and provide global imaging measurements for surface reflectance, water leaving radiance, thermal emissivity, and surface radiance and temperature that will enable science and applications users to advance the current understanding of the Earth's ecology, biogeochemistry, biodiversity, coastal and inland waters, geology, natural hazards, hydrology, climate, and studies of the carbon cycle.

Mission objectives:

- Processes indicating volcanic eruption
- Nutrients and water status of vegetation; soil type and health
- Spectra to identify locations of natural resources
- Changes in vegetation type and deforestation; drought early warning
- Improved exploration for natural resources
- Forecasts of likelihood of volcanic eruptions and landslides

Orbit: LEO, SSO

Instruments: Hyperspectral spectrometer



Architecture/structure

Three year mission, two Instruments on one spacecraft at 626 km 11 am sun sync orbit: (1) Imaging Spectrometer (VSWIR), (2)Thermal Infrared Multi-Spectral Imager (TIR)

VSWIR Science Measurement:

- 380 to 2500 nm in 10nm bands
- 60 m spatial resolution, 19 day revisit
- Global land and shallow water (<50m)

TIR Science Measurement:

- 8 Bands (7 bands between 7.5-12 µm & 1 band at 4 µm)
- 60 m spatial resolution, 5 day revisit
- Global land and shallow water
- Day and night imaging

Data Products

VSWIR Level 2 Products

- Terrestrial Surface Reflectance
- Acquatic Surface Reflectance

TIR Level 2 Products

- Surface Radiance
- Surface Temperature Emissivity